High-Resolution Temporal Sampling of the Nearshore Vertical Structure of Bioluminescence

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LONG-TERM GOALS

My long-term goal is to advance our understanding of the ecology of bioluminescent organisms and the mechanisms governing the temporal and depth-dependent variability of bioluminescence in the coastal ocean. With improvements in technology, finer-scale resolution and concurrent physical, chemical and biological data, I will examine the predictability of bioluminescence events in the nearshore coastal ocean.

OBJECTIVES

I propose to integrate a real-time bioluminescence capability into the existing observation network in the coastal waters off New Jersey. Obtaining high-resolution vertical structure of bioluminescence in conjunction with a suite of ongoing physical, chemical and biological measurements will advance our understanding of the mechanisms governing the temporal and depth-dependent variability of bioluminescence in the coastal ocean. Specifically I propose three objectives:

1 - To adapt, fabricate and deploy a moored bioluminescence system on a robotic node 5 km off the central coast of New Jersey.

2 - To quantify the physical, chemical and biological processes that define the spatial and temporal variability in bioluminescence for the nearshore coastal ocean, focusing on features associated with recurrent coastal upwelling.

3 - To take advantage of the vertical structure time series in conjunction with ancillary measurements to identify the significant bioluminescent organisms and define the physical forcing of phytoplankton communities during summer upwelling events.

APPROACH

As a participating scientist with the Long-Term Ecosystem Observatory (LEO-15) at Rutgers University, my goal was to collaborate with physical/biological oceanographers in integrating a new profiling capability into the existing observational network. In addition to fabrication of the bioluminescence instrument, the general approach was to collect fine structure of bioluminescence

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approximately every 20 minutes and make concurrent measurements for plankton and physical/optical parameters. Concurrent measurements were made of temperature, salinity, and sigma-t (CTD), bioluminescence potential, chlorophyll fluorescence, spectral scattering, spectral absorption, spectral attenuation, particle size/abundance (LISST), irradiance and ADCP.

WORK COMPLETED

Bioluminescence bathyphotometer (BBP) built for this project was recalibrated after the summer 2000 field effort (by UCSB) and was integrated into the optical profiler (Moline and WHOI). Prior to deployment, there were a number of mechanical and electrical issues that needed to be addressed on the profiler. The profiler was then tested in the boat basin at the Rutgers University Marine Field Station (RUMFS) the day before deployment. Deployment for the 2001 field program occurred on 23rd of July in the same location as the previous year at LEO-15. The profiler was connected to the existing nodes for power and data exchange. Direct real-time communication and operation of the profiler and the BP was done remotely through a terminal at the RUMFS. The entire deployment lasted until August 7th for a total of 15 days. Data from the optical profiler was archived into a WetLabs Super MODAPS unit and is presently being extracted for analysis.

RESULTS

A temperature time-series measured by the Node at LEO-15 indicated that during the deployment, the optical profiler was able to collect data through two coastal divergence events with stratification only occurring twice (http://marine.rutgers.edu/cool/hycode2/data/auj06/a_temp.gif). This is similar to the previous years data that showed stratification only during two periods. Addition of the 2001 dataset will augment the 2000 data, allowing for a more robust analysis of the continuing statistical analysis approaches.

For the 2000 data, the water column remained mixed until the 22nd, when an intrusion of cooler water at depth from the shelf pushed up along the coast in response to winds from the southwest (the wind direction responsible for upwelling in the region). This cold-water intrusion ended after three days and was replaced by warm mixed water. From the 25th until the 30th of July, the water column remained mixed and warmed ~1.5 °C. As the surface water continued to warm through August 3rd, the water column stratified and the temperature of the bottom water varied less than 0.5 °C. Over the course of the deployment, surface temperatures warmed from 18 to 24 °C. Bioluminescence potential over the course of the two-week deployment in 2000 showed a full range of vertical distribution, from stratified layers to homogeneous distributions. On the first night of sampling, high bioluminescence signals of 1e^{11} photons/s were associated with cooler water at depth. As the water was advected out of the site, the signal decreased 2 orders of magnitude. This lower signal was also present the following cycle and the distribution of bioluminescent organisms extended from the surface to 14m. As the cold-water intrusion intensified, the bioluminescent communities were strongly stratified and strongly associated with the thermocline break. With the disappearance of the cold bottom water, there was a 3-4 order-of-magnitude decrease in bioluminescence signal. With the warming of the surface layer and stratification in the final 4 days of the experiment, there was the development of another layer of high bioluminescence potential associated with the thermocline. There was a homogeneous distribution on the final day of the study that coincides with a decrease in stratification resulting from increased wind stress. The relationship between stratification and peak bioluminescence potential has been further examined by looking at the correlation of the bioluminescent signal and the buoyancy frequency, which is a measure of the gradient in the density of a water column (Figure 1). Initial results show that

the two are related; however direct correlation is not strong. Statistical methods are presently being developed to examine a possible depth offset between the gradient and the biological community, as organisms are not imbedded within a gradient, but are often on or under these vertical density barriers.

Statistical methods are also being developed to examine the temporal variation in the system. Two non-linear statistical approaches are being evaluated for both the 2000 and 2001 datasets. Bayesian and Markov Chain Monte Carlo modeling approaches will be used as there is a temporal dependence of a particular profile on the previous measurement. A simple method employing a standardized mean difference analysis on the data has been conducted. As predictability is a goal of this project, the temporal dataset from 2000 was used to predict the variability with depth in this region over four time periods (24, 48, 72, and 96 hours). Results show a depth-dependence in the variability with the highest variability of up to 80% occurring in the surface waters within 24 hours. Results from this analysis will be reevaluated when the data from the 2001 season is incorporated.

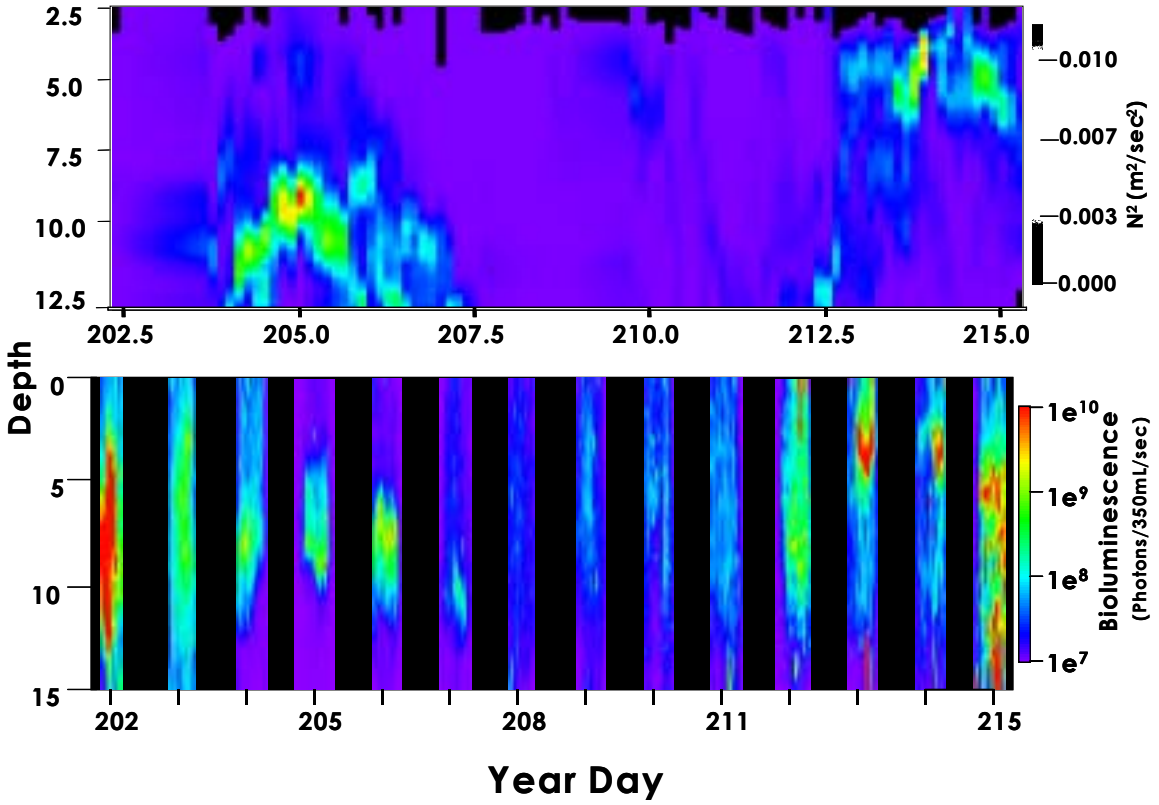

Figure 1. Time series with depth of the buoyancy frequency (upper panel) and bioluminescence potential during the 2000 deployment

Another objective of this project and the Navy has been to predict not only the bioluminescence potential, but also more importantly the leaving radiance. Only through the combined measurement of both optics and bioluminescence potential can this be properly addressed. The optical profiler provides the only system to date with the required optical data to undertake this effort. Combining the

bioluminescence potential and the measured attenuation at 488nm, the leaving radiance was calculated for the entire 2000 deployment (Figure 2). This demonstrates the high degree of variability (4 orders

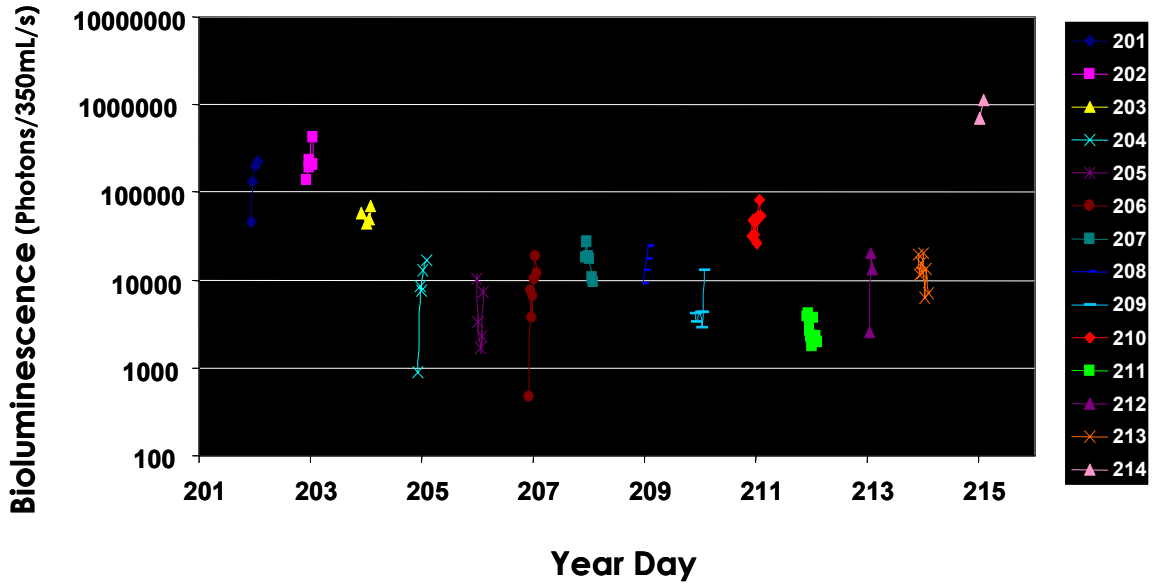

Figure 2. Leaving radiance calculated from bioluminescence at 3.5 m depth from the optical profiler during the 2000 deployment.

of magnitude) in the leaving radiance over the course of two weeks at a single depth and 2 orders of magnitude within 24 hours. For this exercise a simple linear transfer was used however, a recent collaboration between Moline and C. Mobley through the ONR-HYCODE program is presently developing a module for the existing Hydrolight radiative transfer modeling program to provide a highly accurate 3-dimentional transfer function for leaving radiance. This program now uses both input data from both the AC-9 for attenuation and a measured profile of bioluminescence to calculate leaving radiance. Previous versions had an "idealized" bioluminescence distribution with depth. Data from this study clearly illustrates that idealized distributions cannot be applied to highly variable coastal systems. This collaboration is ongoing.

This project was also expanded during the 2001 field season to include the use of the HIDEX instrument to 1) Expand the horizontal scale of sampling to the continental shelf break and 2) to compare the signals between the HIDEX and the smaller bathyphotometers, as used in this study. Sampling of phytoplankton and zooplankton were concurrent with these efforts. Data from these efforts are presently being distributed between groups for analysis.

IMPACT/APPLICATION

From the data collected thus far, it is clear that using this bioluminescence platform will advance the ability to detect fine-scale vertical changes over time. In conjunction with the ancillary measurements it will also provide an opportunity to examine the mechanisms forcing the abundance and distribution

of bioluminescent organisms. The installation and operation were successful and with continual operation, the vertical structure has been examined over a range of time scales from minutes to weeks.

TRANSITIONS

This project adds a new high-resolution nighttime bioluminescence capability to an existing network designed to predict the 3-dimensional structure of coastal currents, water density and in-water optical properties on the time scales of hours. Fine-scale vertical bioluminescent measurements coupled with ancillary physical/biological measurements will improve the ability to predict bioluminescent events in the nearshore littoral regions of the marine environment. The incorporation of optics into this program makes it possible to quantify the leaving radiance over these same time scales. This is vital for Navy interests, as it is the combination of the maximum light and light propagation that will be required for tactical mission planning.

RELATED PROJECTS

1 – The installation and operation of the optical profiler is in collaboration with Chris von Alt (WHOI) and Oscar Schofield (Rutgers University). In addition to directly addressing the objectives above, data products from this profiler will be integrated into the ONR-Hyperspectral Coastal Ocean Dynamics (HyCODE) program of which I am presently a PI (ONR- N000149910197). Collaborations with HyCODE scientist C. Mobley (Sequoia Scientific) will also continue to develop a rapid accurate quantification of leaving radiance when combining optics and bioluminescence measurements. 2 – Collaborations with James Case (UCSB) continued at LEO-15 over the 2001 season in order to further characterize the bioluminescent organisms in the coastal environment. Methods of collection included net sampling and Schindler trap sampling. 3 – Collaborations with E. Widder (HBOI) with the HIDEX will be ongoing over the following year to evaluate the data collected over the 2001 season.

PUBLICATIONS

Moline, M.A., Case, J.F., Herren, C. and Schofield, O. 2001. Spatial and temporal variability of bioluminescence potential in coastal regions, In: *Bioluminescence and Chemiluminescence* (Case, F., Herring, P.J., Robison, B.H., Haddock, S.H.D., Kricka, L.J. and Stanley, P.E., eds.), World Scientific Publishing Company, Singapore, in press.